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# The Livingston Formation of the South Boulder Area

Nelson A. Jones

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THE LIVINGSTON FORMATION  
OF THE SOUTH BOULDER AREA

by

Nelson A. Jones

A Thesis  
Submitted to the Department of Geology  
in Partial Fulfillment of the  
Requirements for the Degree of  
Bachelor of Science in Geological Engineering

MONTANA SCHOOL OF MINES  
Butte, Montana  
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# THE LIVINGSTON FORMATION OF THE SOUTH BOULDER AREA

By

Nelson A. Jones

## GENERAL INFORMATION

The Livingston formation is a thick succession of late Cretaceous lava flows, tuffs, and bedded water-laid volcanic detritus 200 miles long and 100 miles wide lying along the eastern margin of the Rocky Mountains in western Montana from Augusta to Yellowstone Park. It differs markedly within short distances in lithologic character and sequences, and the total thickness may exceed one mile in some places.

\*

The formation was first recognized and described by Weed (14), near Livingston, Montana in 1890, and Stone and Calvert (11) in 1910 determined the Livingston formation to be Upper Cretaceous and early Tertiary in age. The writer is of the opinion that since the volcanics were involved in the Laramide deformation, and also lie on the Colorado formation, they must be of late Cretaceous age.

Since the early studies, little work has been done on the Livingston formation. Literature dealing with the Livingston formation is usually brief and very general. Probably the reason is the complex nature of volcanic rocks, and also there seems to have been an apparent lack of recognition of great economic significance in these volcanic rocks, even though they are the host rock to important mineral veins in certain mining districts.

The Livingston formation as it is found in the South Boulder Creek area is the subject of this thesis. The area is reached by traveling eight miles east of Whitehall on U S Highway 10, and then turning south on seven

\* Numbers in brackets refer to references in the bibliography.



miles of good secondary road which passes through Cardwell and Jefferson Island, stations on the Northern Pacific and the Chicago, Milwaukee, St. Paul and Pacific railways. South Boulder Creek flowing north from the Tobacco Root Mountains enters the Jefferson River three miles north of the area of study where the South Boulder valley widens before uniting with the Jefferson River valley.

The area studied is a combination of cultivated, pasture, and grazing land. Drainage from the west into South Boulder Creek has sculptured the Livingston formation into a series of low east-west ridges, and the different units of the Livingston formation are exposed along these ridges and intervening gullies. Over much of the area the Livingston formation is covered, thereby obscuring much of the detail.

Several days were spent by the writer studying the Livingston formation along the western side of South Boulder Creek valley during the summer of 1948, and plane table and alidade, and Brunton and pacing surveys were made of this area. Considerable time was spent in reconnaissance of the area during which field relationships were studied and numerous hand specimens were collected.

The writer is grateful to Dr. E. S. Perry and other members of the Department of Geology, Montana School of Mines, for guidance and assistance in field work, laboratory study, and in the preparation of this text.

## GENERAL GEOLOGY

### Stratigraphy

The South Boulder area is unique from the geologic standpoint because the whole stratigraphic column for south-western Montana is continuously exposed along the valley. All periods of geologic time are represented except the Ordovician, Silurian, and Triassic which are absent in this part



Table 1. STRATIGRAPHIC COLUMN OF SOUTH BOULDER AREA

SYSTEM	FORMATION	CHARACTER	THICKNESS FEET
Quaternary	Alluvium	Sands, gravels, and muds.	
Tertiary	Lake Beds	Loosely cemented sands and gravels.	
Upper Cretaceous	Livingston	Series of Andesites and conglomerates.	3,500+
-----Unconformity-----			
	Colorado	Thin gray shales.	210
Lower Cretaceous	Kootenai	Gray shales and sandstone containing fine chert.	580
Jurassic	Morrison	Variegated shales.	210
	Ellis	Sandstone, limestone, and shale.	110
-----Unconformity-----			
Permian	Phosphoria	Black sandstone and shale.	130
Pennsylvanian	Quadrant	Hard vitreous quartzite.	170
	Amsden	Blue limestone under-laid by red shale.	230
Mississippian	Madison	Very pure, hard, massive, light colored limestone.	1,310
	Mission Canyon		
	Madison	Very dense, black, fine grained limestone.	900
	Lodgepole		
Devonian	Three Forks	Sandy, grayish-green, fossiliferous shale.	520
	Jefferson	Black, sandy, crystalline, fetid dolomite.	870
-----Unconformity-----			
	Dry Creek	Reddish-brown, sandy shale.	160
	Pilgrim	Mottled limestone in two tones of gray.	310
Cambrian	Park	Green, micaceous, argillaceous shale.	130
	Meagher	Mottled black and light colored magnesium limestone.	410
	Wolsey	Green argillaceous shale.	310
	Flathead	Hard, vitreous quartzite.	130
-----Unconformity-----			
Pre-Cambrian	Belt	Shale, arkose, and conglomerate.	5,000
	Pony	Schists and gneisses.	?



of Montana. (The stratigraphic column for this area is shown in Table 1). A study of the succession of formations is further facilitated by a uniform northward dip of 35 to 50 degrees parallel to the creek valley which is followed by a good gravel road.

The Livingston formation lies at the north end of this continuously exposed sequence. The Livingston is also exposed three miles west of South Boulder valley, east and south of the Mayflower Mine. Although the general lithology of the lavas in this area is similiar to the South Boulder area, the sequences differ.

#### Structure of Area

The main structural feature of the South Boulder area is a large syncline which involves all strata from Pre-Cambrian through Cretaceous. Tertiary lake beds overlap the older strata. The axis of the syncline has a bearing of S.  $75^{\circ}$  E. and plunges to the west. The south limb of this syncline is well exposed along the South Boulder valley. The Cambrian strata dip toward the north at 50 degrees, and the dip decreases as the strata become younger. The contact between the Colorado and Livingston formations has a dip of 40 degrees, and the dips decrease rapidly until the uppermost unit of the Livingston formation is nearly horizontal. The northern limb of the syncline has a very steep dip and is highly faulted, however this northern limb is beyond the area studied.

One of the major faults in the area, which can be traced for several miles, is the Mayflower fault passing west of South Boulder Creek valley, and trending N.  $70^{\circ}$  E. Near the Mayflower Mine this fault throws the Pre-Cambrian Belt against the Livingston lavas, indicating a stratigraphic throw of between one and two miles.



Northeast of the Mayflower Mine a series of en 'echelon faults displace the lower Paleozoic strata north of the Mayflower fault. South of the Mayflower fault there are several faults, nearly parallel to the Mayflower fault, displacing the upper Paleozoic and Mesozoic strata.

North and east of the South Boulder area several faults trend from east to west.

The Livingston formation outcrop area studied lies adjacent to and between these fault zones and possibly is influenced by these faults.

#### Relationships

Berry (1:22) in his Three Forks report states, "The stratigraphic position and structure of the Livingston indicates that it was formed during volcanic activity which accompanied the Laramide revolution. In the Three Forks area, it has been folded with the underlying strata, though apparently not so intensely and must therefore, have been formed before the deformation was completed."

Berry (1:22) following Stone and Calvert says that, "According to Stone and Calvert (1910) the Livingston formation in the area to the east is equivalent to the Clagett, Judith River, Bearpaw, and Lennup formations of Upper Cretaceous and to the Eocene Lance and lower Fort Union."

The Livingston formation rests unconformably upon older strata. Apparently the Livingston was laid down on a nearly level erosion surface. This can readily be seen south of the Mayflower Mine. The Livingston partially covers the Kootenai and extends over eroded edges of the Morrison, Ellis, and Phosphoria formations, and when last to be seen lies on the Quadrant formation.\* (Pl. V)

\*Perry, E. S., oral communication.



The Livingston formation lies on top of the Colorado formation and since these volcanics were involved in the Laramide deformation they must be of late Cretaceous age.

The Livingston formation is folded along with older strata, and it is also faulted along with them, and in some areas the stratigraphic throw is between one and two miles. This folding and faulting occurred during the Laramide deformation.

#### THE LIVINGSTON FORMATION

The area in which the Livingston formation was studied lies in sections 2, 3, and 4 of T. 1 S., R. 3 W. and sections 26, 34, and 35 of T. 1 N., R. 3 W. The area is two and one half miles long, and one half to one mile in width. Approximately 75 percent of this area is covered with soil, but good outcrops are found along the eastern border of this area, and it is there that the various units of the Livingston formation were studied. (Pl. VI)

The Livingston formation has been referred to as either andesites or basalts. This may be due to the particular system of rock classification which was used. All of the plagioclase was found to be within the andesine range. Therefore, using Johannsen's system of classification of rocks, all the lavas have been tentatively called andesites by the writer.

The terms agglomerate and conglomerate have been used in describing parts of the Livingston formation. The clastic portions in the South Boulder area have well rounded pebbles; and the finer material, while not stream worn, suggest mud flows or reworking by water. The clastic beds are tentatively called conglomerates and are of andesitic material.

The writer has tentatively subdivided the Livingston formation in this area into seven units which are easily distinguishable. The total thickness of these units is over 3,500 feet. Diagnostic features of these units are given in Table 2.



Table 2.

## UNITS OF THE LIVINGSTON FORMATION

UNIT	CHARACTER	APPROXIMATE THICKNESS FEET
G	Brownish-pink andesite with andesine phenocrysts, viscous slag appearance.	100+
F	Reddish-brown andesite with scattered andesine phenocrysts, slate-like or slag-like in appearance.	500
E	"Oatmeal Rock", brown andesite with white platy andesine phenocrysts.	800
D	Andesitic conglomerate, light matrix, colored pebbles, needle-like hornblende crystals in pebbles, similiar to Unit A.	300
C	Light gray fine-grained andesite, some augite phenocrysts, makes up most prominent hogback of Livingston.	400
B	Reddish-brown fine to medium grained andesite, many small andesine, augite, and hornblende phenocrysts.	500
A	Andesitic conglomerate, light matrix, pebbles may be several inches in diameter, elongated hornblende crystals in pebbles, similiar to Unit D.	900

## Description of Units

In describing the units, field relationship, megascopic, and microscopic observations are recorded. All units have been subjected to considerable weathering. Furthermore, the groundmass, which makes up the large portion of these units, is very fine-grained, highly altered, and the exact mineralogy is difficult to determine. The groundmass in much of the upper part of the series appears to be in part glass, and in part devitrified glass; and this condition no doubt is responsible for difficulties in mineral identifications.

Unit A.

At the base of the series is a mass of conglomerate consisting of approximately 900 feet of andesitic material which rests unconformably upon the Colorado shale and older strata. This unit is well exposed at



the power line intersection and in the gully just to the north. (Pl. I A.) The dip at the Livingston-Colorado contact is approximately  $40^{\circ}$  N. Well exposed in the gully is a series of relatively thin beds, less than twelve inches thick, which dip to the south at approximately 15 degrees. (Pl. III, B) This is inconsistent with the general north dip, and suggests cross bedding or foreset beds of a delta type of deposit.\*

The matrix of this unit is a light-gray, fine-grained material which is suggestive of cement. Small platy crystals of white plagioclase are the only recognizable mineral from the hand specimen. The pebbles of this unit are characterized by fairly abundant thin elongated black hornblende crystals which may be a half inch in length and have no apparent orientation. (Pl. III, C) The matrix of the pebbles is similiar to the matrix of the conglomerate. The pebbles are sub-rounded and some are several inches in diameter. (Pl. III, A)

From a thin section of the matrix of the conglomerate the approximate percentages are; 70 percent extremely fine grained groundmass mostly plagioclase, 25 percent andesine phenocrysts, and the remaining 5 percent hornblende, augite, magnetite, and a trace of quartz. Inclusions of magnetite are common in augite and hornblende crystals. The mafic minerals are highly altered. The pebbles have a much greater proportion of the mafic minerals. The approximate percentages are; 70 percent extremely fine-grained groundmass mostly plagioclase, 10 percent andesine phenocrysts, 10 percent hornblende, 5 percent augite, 5 percent magnetite and a trace of quartz. The magnetite is usually associated with hornblende or augite.

\*Perry, E. S., oral communication.



### Unit B.

Above the basal conglomerate is a unit consisting of approximately 500 feet of reddish-brown andesites. The upper portion of this unit makes up the first small ridge or hogback north of the power line intersection.

The upper portion of this unit is richer in the mafic minerals and somewhat coarser grained than the lower portion. The exact mineralogy is difficult to determine in the hand specimen.

As seen in thin section the approximate percentages are; 60 percent very fine-grained black and white groundmass, 20 percent andesine phenocrysts, 10 percent augite, 7 percent magnetite, and 3 percent hornblende. The mafic minerals are altered and gives a red-brown color to the hand specimen and outcrop.

### Unit C.

The third unit consists of approximately 400 feet of andesite and makes up the most prominent ridge or hogback in the area studied. (Pl. I, B) The dip is  $35^{\circ}$  N. and the strike is S.  $75^{\circ}$  E. From a distance the outcrop appears to be light green.

In the hand specimen the rock is light gray with scattered green augite phenocrysts. An unweathered specimen taken from the dump of an irrigation ditch tunnel is dark gray. Some specimens have amygdules which are "tear-drop" shape.

From thin section about 95 percent of the rock is extremely fine-grained groundmass mostly plagioclase. The mafic minerals, augite and magnetite, make up the other 5 percent. Small apatite crystals are found in some of the augite crystals. A trace of quartz is present.



#### Unit D.

This unit, which is similiar to unit A, consists of about 300 feet of conglomerate. The hornblende in the pebbles appears to be more needle-like than that found in the first unit. Some of the pebbles have a green or purple hue which was not so evident in the first unit.

The approximate percentages from a thin section are; 70 percent very fine-grained light gray groundmass, 15 percent andesine phenocrysts, 10 percent hornblende, 3 percent quartz some of which is suggestive of chalcedony, 2 percent augite, and a trace of magnetite. The hornblende is slightly altered. (Pl. IV, A)

#### Unit E.

Above the second conglomerate is a unit consisting of 800 feet of andesite which has the very popular descriptive name of "Oatmeal Rock". Once you are familiar with this rock you recognize it instantly when seen again. The dip of this unit is  $28^{\circ}$  N.

The white plagioclase phenocrysts stand out in the brown fine-grained groundmass. The thin oval discs of plagioclase are suggestive of oatmeal flakes. (Pl. III, E)

From thin section approximately 75 percent is the fine-grained groundmass and 25 percent is andesine phenocrysts. The groundmass is very fine-grained and consists of plagioclase and undeterminable mafic minerals. Some chlorite is present. The groundmass, under high magnification, is suggestive of a diabasic texture. (Pl. IV, C and D)

#### Unit F.

This unit consists of 500 feet of andesites which make up three rounded hills which are close together. The dip of the unit is  $15^{\circ}$  N. Some rocks have a slate-like appearance while others suggest a slag.



The slag-like material has many smooth and slightly warped surfaces probably resulting from cooling fractures.

The unit is made up of brown or reddish-brown massive andesite with scattered plagioclase phenocrysts.

In thin section 15 percent is recognized as andesine phenocrysts. The remainder is a very fine-grained groundmass. Altered undeterminable mafic minerals give the color to the unit. Some magnetite is present.

#### Unit G.

The top unit consists of over 100 feet of andesite vitrophyr. The approximate dip is 2 to 10° N.

The groundmass of this unit is brown-pink and has scattered irregular plagioclase phenocrysts in it. (Pl. III, D) The groundmass has a viscous slag appearance suggesting flow structure. Elongated vesicles are not uncommon in this unit.

The excellent flow structure in the groundmass stands out in a thin section. Under crossed nicols the groundmass is dark suggesting a glassy or vitrophyr texture with some devitrification. (Pl. IV, E and F) Small veinlets of quartz are common in the groundmass. The phenocrysts, which are andesine, make up approximately 25 percent of the rock.

#### Description of Specimens

In addition to the units, the writer found several outcrops which are a part of the Livingston formation, but which are not readily distinguishable or consistent with the previously named units. These have been designated as specimens and their position at the extreme top of the series has been noted by specimen letter on the map. (Pl. VI) These specimens are described below.



Specimen (E) is an andesite containing irregular white plagioclase phenocrysts in a gray-brown, very fine-grained groundmass. From a thin section the approximate percentages are; 20 percent andesine phenocrysts, 15 percent hornblende, a trace of quartz, and the remainder is the groundmass. (Pl. IV, B)

Specimen (G) is a brownish-green porous rock, and has the appearance of a sugary texture. Augite phenocrysts are prominent in the hand specimen.

In thin section, augite and magnetite comprise about 25 percent of the rock. The remainder is a fine-grained gray-white groundmass. There is some magnetite in the groundmass.

Specimen (H) is from another conglomeritic outcrop which is reddish-purple in color, and very similiar to Units A and D. The outcrop is well exposed in one of the numerous gullies north of the center of section 35, and north of a prospect shaft in the northwest quarter of this section.

Specimen (J) is a deep-red slag-like rock showing flow structure both in outcrop and hand specimen. In thin section the specimen is too fine grained and altered for determination of minerals and it may be a devitrified glass.

Specimen (N) comes from a large bluff northeast of the prospect shaft in section 35. It resembles a fine-grained red sandstone, and alteration has produced darker bands of red suggesting bedding. Cooling fractures are numerous but have no apparent system. In thin section it is too fine-grained and altered for mineral determination.

Specimen (O) is similiar to (N) except that the color is a light green. It appears to be banded, and splits along these bands of clay-like material when wet. In thin section it is too fine-grained and altered for mineral determination.



Specimen (R) is a reddish-brown rock which is similiar to the upper portion of Unit B. This rock is found in a conglomerate composed of similiar material. This type of rock extends for several hundred feet along the northeast border of the outcrop area of the Livingston formation. (Pl. II, C)  
A thin section was not made of this specimen.

#### Structure of the Livingston Formation

The Livingston formation rests unconformably upon older strata as has been brought out previously.

Unit A lies unconformably on the Colorado and Kootenai formation, and successive units through G. occur in regular succession to the center of section 35. The dip of all units gradually decreases toward the north as the center of the large syncline is approached. At the basal Livingston-Colorado contact the dip is approximately  $40^{\circ}$  N., Unit C has a dip of  $35^{\circ}$  N., Unit E has a dip of  $28^{\circ}$  N., Unit F has a dip of  $15^{\circ}$  N., and Unit G has a dip of perhaps 2 to  $10^{\circ}$  N. The thickness of the Livingston formation was determined from a cross section based on these dips. (Pl. VI)

These units are all on the south limb of the large syncline in the area, although Unit G is very close to the center of this syncline.

In the southeast quarter of the northwest quarter of section 35 a segment of Unit E dips  $45^{\circ}$  SE. The contact between this portion of Unit E and the underlying volcanics is circular in shape. (Pl. I, C, II, A, and VI)

This segment of Unit E is quite different from the unit as found in the regular sequence. The "Oatmeal Rock" has been fractured and fissured and the rock has been replaced by secondary mineralization, primarily bright-red, bright-green, and brown cryptocrystalline varieties of quartz. A few large calcite and quartz crystal are also found. Many of the plagioclase phenocrysts have been altered and distorted. A prospect shaft and several pits in the northwest quarter of section 35, are sunk in this segment of Unit E.



A probable fault is located near the drainage in the center of section 35 and trends from east to west. This segment of Unit E has been raised and tilted southeast relative to Unit G.

#### Undifferentiated Area

Conformable under the tilted segment of Unit E is a thin conglomerate similiar to Unit D. Just north of the drainage and west of this contact but within 300 feet of the contact are several small scattered outcrops. These outcrops are of Units D, F, and G, and all apparently seem to be in place. This is inconsistent on the basis of the sequence of the units outlined unless explained by faulting.

North of the prospect shaft north of the center of section 35 are several specimen locations and all of these specimens, except the conglomerate (H), are foreign and inconsistent when compared to the sequence of the units.

The writer can only suggest some possible explanations for this undifferentiated area north of the center line of section 35.

The area may be highly faulted. This is reasonable after looking at the map (Pl. V) which shows numerous faults just to the west in sections 27, 28, 33, and 34 of T. 1 N., R. 3 W. There are also known faults northeast of this area. It is unlikely that the Livingston formation would be unfaulted while adjacent areas are highly faulted.

From a study of other maps of the area a portion of the north limb of the large syncline could possibly be found in this area. If such is the case one would reason that some of the lower units would be recognizable in this area. Specimens (H) and (R) could possibly be portions of these lower units.



On the other hand, the rocks in this area could be different flows of volcanic material; or again it is possible that the rocks in this area could have been subjected to a more or less intense degree of alteration.

Many factors may be important such as; chemical composition, viscosity, temperature, distance traveled, thickness of flow, and rate of cooling.

The answer to this undifferentiated area probably lies in a combination of two or more of the mentioned possibilities modified by one or more of the factors mentioned.

#### SUMMARY AND CONCLUSIONS

The Livingston formation was laid down on a nearly level erosion surface in late Cretaceous time, later than deposition of Colorado shale.

The Livingston formation was folded and faulted during the Laramide deformation, hence must be earlier in age than Laramide deformation.

The Livingston formation in this locality consists of at least seven units of andesites and conglomerates which total over 3,500 feet in thickness.

An undifferentiated group of rocks at the north end of the area presents a problem and needs further study.

This is not the complete story of the Livingston formation, however it is another step towards that objective.

Chemical analysis, more detailed petrographic study, and correlation with the Livingston formation in other areas would be desireable in additional study of the Livingston formation.



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# PLATE I

- A. View looking northeast from the power line intersection. Unit A conglomerate is exposed in gully. In the right background is an isolated outcrop of Unit C dipping north.
- B. View looking north from Unit A. First ridge is upper portion of Unit B. The second and most prominent ridge is Unit C.
- C. View looking north from top of Unit C ridge. The narrow outcrop in right foreground is the base of Unit E.





A



B



C



PLATE II

- A. View looking north from Unit F ridge. The small outcrop in the center is of Unit G. The dark portion at the foot of the large hill in the background is faulted segment of Unit E.
- B. View looking north from prospect shaft in center of section 35. The large outcrop at the right is of Specimen (N). Specimens (E), (G), and (H) are in successive gullies in the foreground.
- C. View showing outcrops of Specimen (R) near the northeast border of the Livingston formation outcrop area.





A



B



C



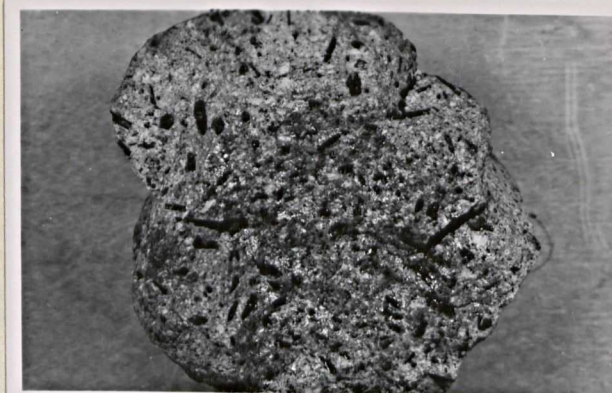
PLATE III

- A. View showing conglomerate Unit A as exposed in gully north of the power line intersection.
- B. View showing south dipping beds of Unit A as exposed in gully north of the power line intersection.
- C. Small pebble from Unit A. (actual size)
- D. Portion of hand specimen of andesite vitrophyre of Unit G. (actual size)
- E. Small hand specimen of "Oatmeal Rock" of Unit E. (actual size)





A



C



D



B



E



PLATE IV

- A. Photomicrograph of Unit D showing hornblende and quartz in fine-grained groundmass. (X nicols.) (40x)
- B. Photomicrograph of Specimen (E) showing zoned plagioclase, hornblende, and quartz in fine-grained groundmass. (X nicols.) (40x)
- C. Photomicrograph of Unit E showing andesine phenocrysts in fine-grained groundmass. (13x)
- D. Photomicrograph of Unit E showing same spot as C. (X nicols.) (13x)
- E. Photomicrograph of Unit G showing flow structure of glass and andesine phenocrysts. (13x)
- F. Photomicrograph of Unit G showing same spot as E. (X nicols.) (13x)

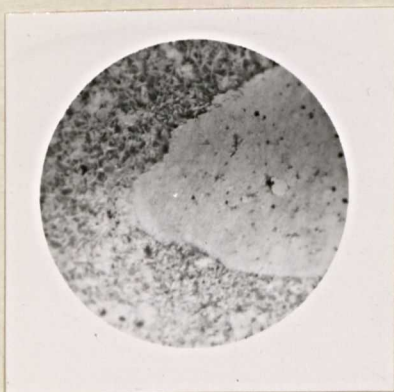




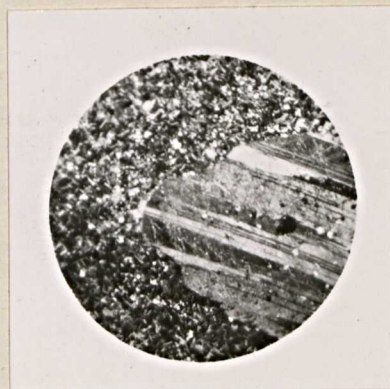
A



B



C



D

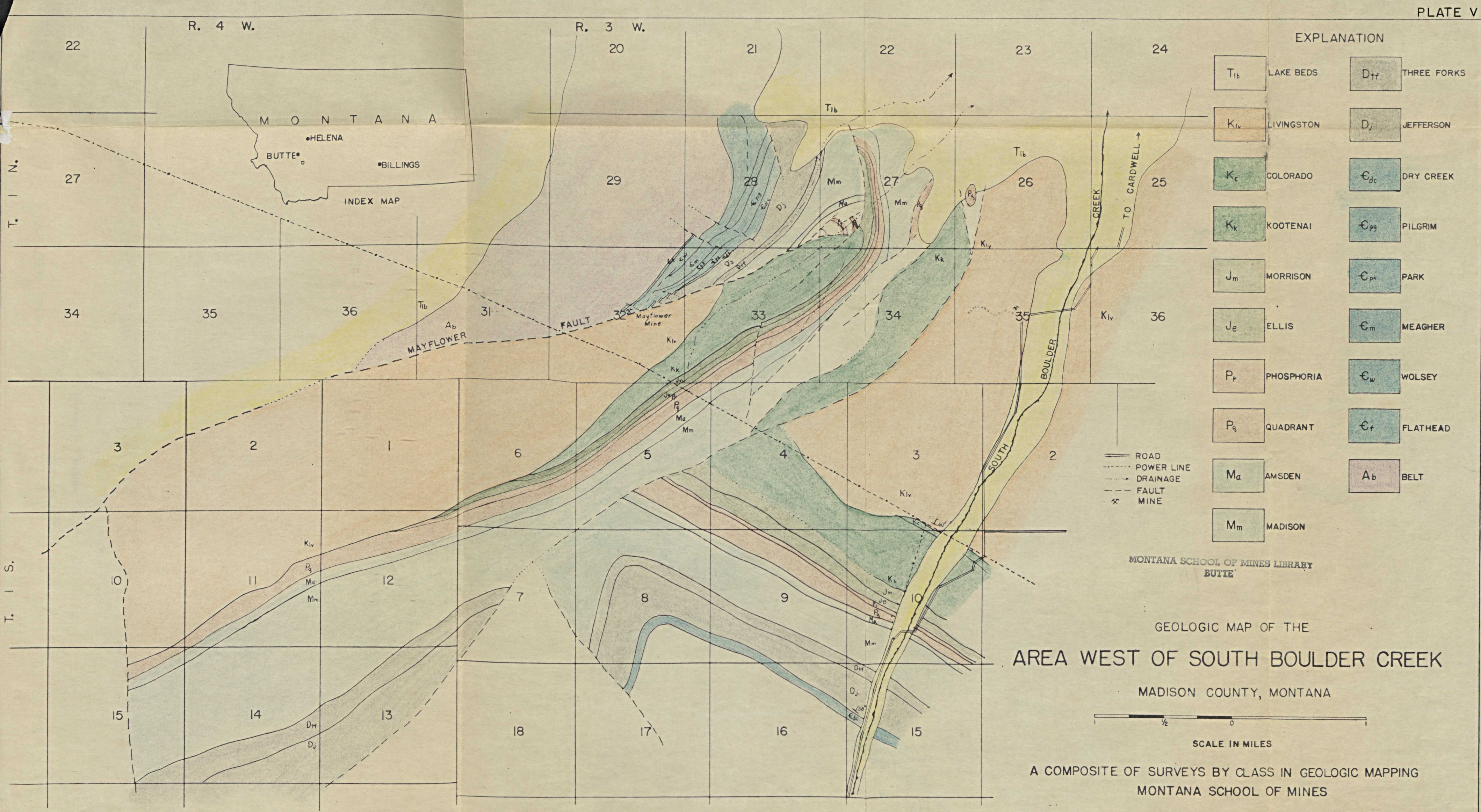


E



F

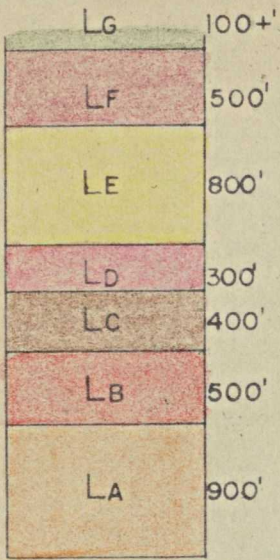




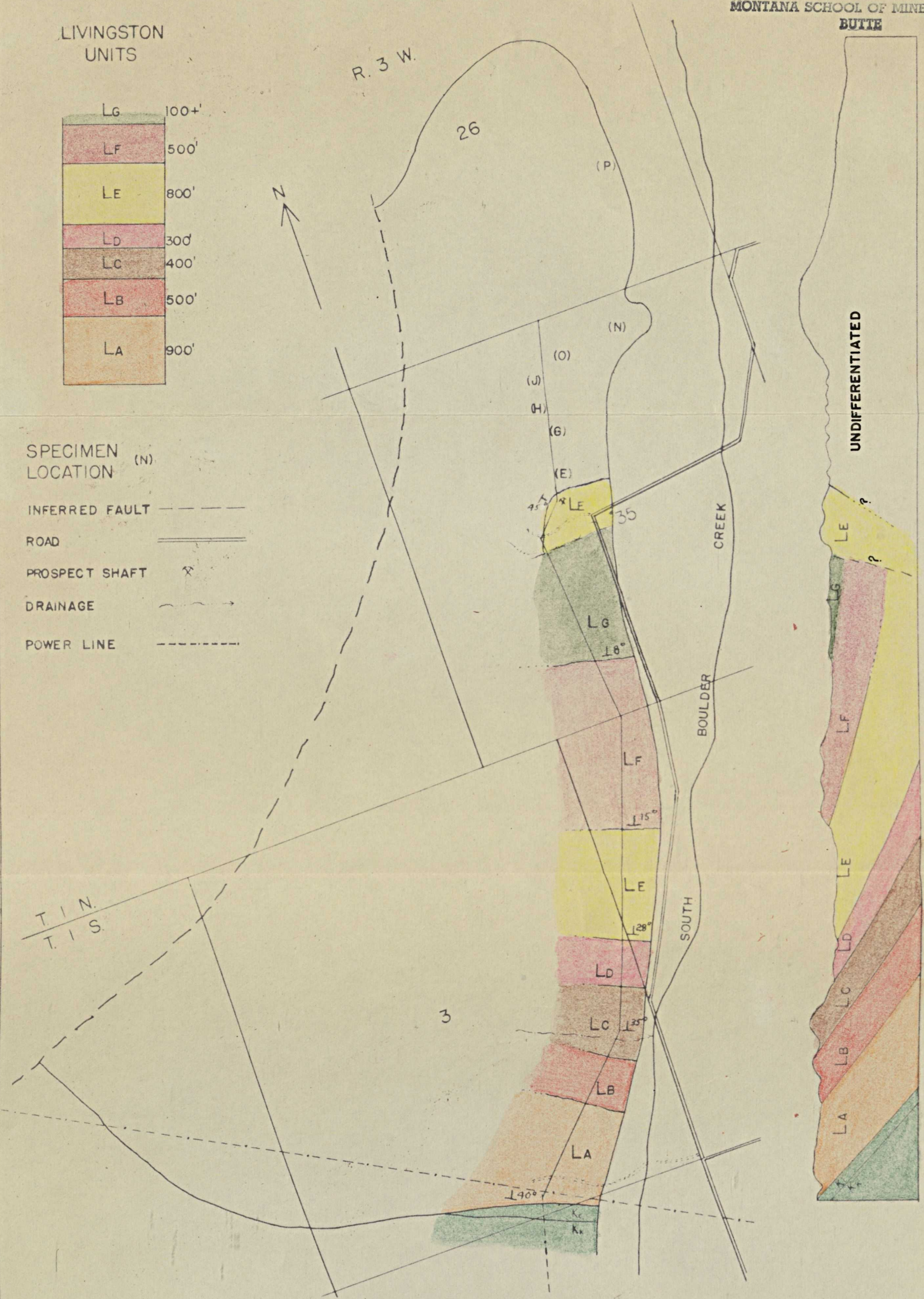
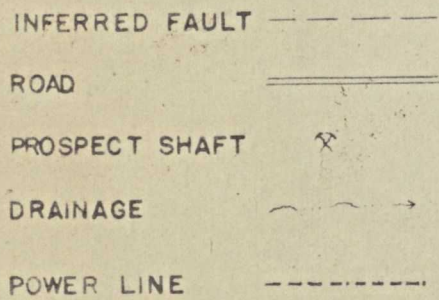


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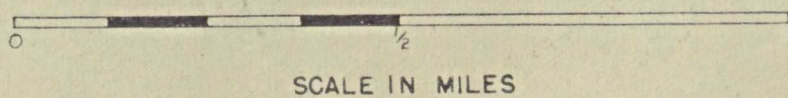
LIVINGSTON  
UNITS



SPECIMEN  
LOCATION (N)



GEOLOGIC MAP OF THE  
LIVINGSTON FORMATION OF THE SOUTH BOULDER AREA  
MADISON COUNTY, MONTANA



OCTOBER 1948

BY NELSON A. JONES

CROSS SECTION ALONG LINE OF TRAVERSE

MONTANA SCHOOL OF MINES LIBRARY  
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